



Upper Ogmore Wind Farm Carbon Balance Assessment

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1. EXECUTIVE SUMMARY

- 1.1 This report has been produced to assist consultees with their review of the proposal's impact on the existing peat body within the proposed site, and to assess the impact in terms of carbon dioxide (CO₂) emissions against the total potential carbon savings attributed to the proposed development.
- 1.2 The carbon assessment for the proposed development was undertaken using Version 2.8.1 of the Scottish Governments carbon calculator tool. As no tool exists specifically for Welsh wind farms, it is deemed appropriate to use this tool.
- 1.3 Expected values were determined following detailed site assessment and infrastructure design and were input into the carbon calculator tool.
- 1.4 The carbon calculator analysis revealed that the expected potential annual energy output of the 7-turbine proposed development is 82,782 MWh yr⁻¹, with minimum and maximum potential outputs at 77,263 MWh yr⁻¹ and 88,301 MWh yr⁻¹.
- 1.5 The wind farm CO₂ emissions savings over other types of generation (i.e. coal-fired, grid-mix, fossil fuel-mix) is calculated by multiplying the above energy output of the development by the emissions factor of the other types of generation. The figure calculated for the total net emissions of CO₂ lost by the proposed development is then divided by the wind farm CO₂ emissions savings over the other individual types of generation, to reveal the payback time for the proposed development.
- 1.6 Based on the expected energy output of the development (82,782 MWh yr⁻¹), and the emissions associated with the development, the potential expected tonnes of CO₂ emissions saved per year over coal-fired electricity generation is 74,138 tCO₂; grid-mix generation is 21,396 tCO₂ and fossil-fuel mix is 36,224 tCO₂.
- 1.7 The conclusion of the carbon calculator reveals that the proposed wind farm will effectively pay back its expected carbon debt from manufacture, construction, impact on habitat and decommissioning within 1.7 years, if it replaces the fossil fuel electricity generation method. Based on the minimum and maximum scenarios, the analysis shows that the payback time for fossil fuel-mix generation ranges between 1.1 and 3.2 years and illustrates that the proposed development will generate 31.8 years' worth of clean energy based on the maximum worst-case value.
- 1.8 Various conservative assumptions are included in the calculation thereby overestimating the impact to the peat. It is assumed that all peat is removed from the excavation areas of turbine foundations and no benefit is taken from reinstatement. In reality, large areas of the site will be reinstated immediately after construction, including some of the areas above foundations and any borrow pits used.

2. INTRODUCTION

- 2.1 This report outlines the total carbon balance for the proposed Upper Ogmores Wind Farm (consisting of 7 turbines), including the assumptions made for the calculations that have been undertaken. It has been produced to assist consultees with their review of the proposal's impact on the existing peat body within the proposed site, and to assess the impact in terms of carbon dioxide (CO₂) emissions against the total potential carbon savings attributed to the proposed development.
- 2.2 Accordingly, the carbon assessment for the proposed development was undertaken using Version 2.8.1 of the carbon calculator tool, produced by the Scottish Government. Where applicable, updated recommended values have been taken for the online tool which replaces this spreadsheet.¹
- 2.3 Where relevant, use of the carbon calculator and the associated guidance² including 'Calculating Carbon Savings from Wind Farms on Scottish Peatlands - A New Approach' (Nayak *et al.*, revised December 2010) has been adhered to. In addition, the completion of the carbon balance assessment for the proposed development required input from hydrology, ecology and site investigation specialists to feed information into the carbon calculator.
- 2.4 In the calculation sheet, numbers representing the sources/comments for input values within the Core Input Data sheet of the tool have been placed into the 'Record source of data' column and are explained in Table 1.1 below:

Table 2.1 Source of Data

Number	Input	Source/Comment
1	Lifetime of windfarm	As per planning application
2	Turbine capacity	Site specific modelling
3	Capacity factor	Site specific modelling
4	Extra capacity required for back up	Default value
5	Additional emissions due to reduced thermal efficiency of the reserve generation	Default value
6	Type of peatland	Advised by Engineer
7	Average air temp. at site	Input not required for IPCC method of calculation (refer to 3.23)
8	Average depth of peat at site	Informed by site peat probing 02959D2102; Peat Depth Map

¹ Available online from: <http://informatics.sepa.org.uk/CarbonCalculator/> (last accessed 08/10/18)

² Available online from: <http://www.scotland.gov.uk/Topics/Business-Industry/Energy/Energy-sources/19185/17852-1/CSavings> (last accessed 06/11/2012)

Number	Input	Source/Comment
9	C content of dry peat	Default values in online tool
10	Extent of drainage	Typical
11	Average water table depth	Input not required for IPCC method of calculation (refer to 3.23)
12	Dry soil bulk density	Default values in online tool
13	Time for generation of bog plants	Default values
14	Carbon accumulation due to C fixation by bog plants	Default values in online tool
15	Coal-fired emission factor	Default values in online tool
16	Grid mix emission factor	Default values in online tool
17	Fossil fuel mix emission factor	Default values in online tool
18	Foundation & Hard standing areas	Informed by site design
19	Length of floating roads	Informed by site design
20	Road width	Informed by site design
21	Length of excavated roads	Informed by site design
22	Average depth of peat excavated for road	Informed by site peat probing Figure 8.1 in Volume 3; Peat Depth Map
23	Length of rock filled roads	Rock filled roads not proposed for this application
24	Length of cable trenches	Cables to site below peat and so will result in no permanent displacement of peat
25	Additional Peat Excavation	Informed by site design - this includes the area of the substation and temporary construction compound / final energy storage system
26	Restoration of site after decommissioning	Although restoration will occur, this is neglected due to uncertainties

3. CONTRIBUTION TO CLIMATE CHANGE TARGETS: THE CARBON IMPACT OF THE WIND FARM

Wind Farm CO₂ Emission Savings

- 3.1 The amount of CO₂ emissions produced during energy production varies with the type of fuel used; therefore, the potential CO₂ savings from the proposed development depends on the type of fuel it replaces.

- 3.2 Wind farm CO₂ emissions savings over other types of generation (i.e. coal-fired, grid-mix, fossil fuel-mix) are calculated by multiplying the energy output of the wind farm development by the emissions factor of the other type of generation. The counterfactual emission factors for different energy generation sources is taken from the latest recommended values in the online calculator tool. The coal-fired and fossil fuel values originate from DUKES data³. The grid mix is taken from the list of emission factors used to report on greenhouse gas emissions by UK organisations published by DECC⁴.

Table 3.1: Counterfactual emission factors

Fuel mix	Counterfactual emissions factor (t CO ₂ MWh ⁻¹)
Coal-fired plant	0.918
Grid mix	0.28088
Fossil fuel mix	0.460

- 3.3 The net emissions of CO₂ of the proposed development is calculated by deducting the total CO₂ gains produced by improvement of the site from the total CO₂ emissions lost from construction of, and impacts on peat from, the individual elements of the proposed development (described in the following paragraphs). Then, the net CO₂ emissions lost figure is then divided by the wind farm CO₂ emissions savings over the other individual fuel types calculated, to reveal the payback time. It is considered that coal-fired and grid-mix emissions represent the best and worst-case scenarios respectively, and are reported at the end of each subsection, where applicable.
- 3.4 The expected potential annual energy output of the proposed development is 82,782 MWh yr⁻¹ (based on a 3.6MW turbine model at 37.5 % CF), with minimum and maximum potential outputs at 77,263 MWh yr⁻¹ (3.6MW at 35% CF) and 88,301 MWh yr⁻¹ (3.6 MW at 40% CF).
- 3.5 The carbon calculator reports the wind farm CO₂ emissions saving compared to those emissions from coal-fired, grid-mix and fossil-fuel electricity generation. Based on the expected annual energy output of the development (82,782 MW yr⁻¹), the potential expected tonnes of CO₂ emissions saved per year over coal-fired electricity generation is 75,994 t CO₂; over grid-mix generation is 23,252 t CO₂ and over fossil-fuel mix is 38,080 t CO₂.

³DBEIS, Digest of United Kingdom statistics 2018, Available online from:
<https://www.gov.uk/government/statistics/digest-of-uk-energy-statistics-dukes-2018-main-report>
(Last accessed 09/10/18)

⁴DBEIS, Conversion factors 2018, Available online from:
<https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2018>
(Last accessed 09/10/18)

Emissions due to Turbine Life

- 3.6 Energy is consumed and associated carbon dioxide (CO₂) emissions are released during manufacture of the turbine components, construction of the site (including site tracks and turbine foundations etc), and during the decommissioning of the development.
- 3.7 The energy costs of wind farms in Europe have been assessed in detail by a number of reports⁵. The carbon calculator combines findings from these reports to estimate the global direct and indirect use of manufacture, installation, operation, maintenance and decommissioning of wind farms. It estimates that the net lifetime energy use (electricity equivalent) can be determined with the following formula.

$$\text{Emissions (tCO}_2\text{)} = (934.35 \times \text{Turbine capacity (MW)}) - 467.55$$

- 3.8 The carbon calculator reveals an expected emissions figure of 20,411 tonnes of CO₂ (tCO₂) emitted due to the manufacture, construction and decommissioning of the turbines and foundations to be used in the proposed development.

Capacity required due to Back Up

- 3.9 In order to maintain security of supplies, a second-by-second balance between generation and demand must be maintained by the grid operators. It has been noted that the inherent variable nature of wind energy may affect this balance and therefore, a certain proportion of power is required to stabilise the supply to the customer. The electricity system however, is designed and operated in such a way as to cope with large and small fluctuations in supply and demand. No power station is totally reliable, and demand, although predictable to a degree, is also uncertain. Therefore, the system operator establishes reserves that provide a capability to achieve balance, given the statistics of variations expected over different time scales. The variability of wind generation is but one component of the generation and demand variations that are considered when setting reserve levels.
- 3.10 It should also be noted that an individual wind turbine will generate electricity for 70-85% of the time⁶, and its electricity output can vary between zero and full output in accordance with the wind speed. However, the combined output of the UK's entire wind power portfolio shows less variability, given the differences in wind speeds over the country as a whole. Whilst the amount of UK wind generation varies, it rarely, if ever, goes completely to zero, nor to full output at the same time throughout the UK.
- 3.11 The extra capacity needed for back-up power generation is currently estimated to be 5% of the rated capacity of the wind plant if UK wind power contributes more than 20% to the National

⁵ Lenzen, M., Munksgaard, J. (2002). Energy and CO₂ life-cycle analyses of wind turbines Review and applications. *Renew. Energy*. 26, 339-362.

Ardente, F., Beccali, M., Cellura, M. and Brano V.L. (2008). Energy performances and life cycle assessment of an Italian wind farm. *Renewable and Sustainable Energy Reviews* 12, 200-217.

Vestas (2005). Life cycle assessment of offshore and onshore wind power plants based on Vestas V90-3.0 MW turbines. Vestas Wind Systems A/S Alsvej 21, 8900 Randers, Denmark, https://www.vestas.com/~media/vestas/about/sustainability/pdfs/lca_v90_june_2006.ashx .

⁶Available online from: <https://www.renewableuk.com/page/WindTurbines> (last accessed 09/10/18).

Grid⁷. In 2017 Renewable electricity represented 27.9 % of total generation⁸. In future, interconnectivity and an increase in energy storage may reduce this back up requirement.

- 3.12 This reserve energy represents the additional energy that could have been generated by the conventional generator, but was not specifically due to the need to hold that availability as reserve for wind. The remaining output of the conventional generators will therefore be delivered at lower efficiency as most conventional generators are designed to give maximum efficiency at maximum output. The additional carbon emissions due to backup power generation are therefore created due to the efficiency reduction between full output and reduced output to provide the same total energy. This depends on the type of generator used to provide the backup. Here it is assumed that fossil fuel provides the backup, although the payback time is calculated assuming the different counterfactual cases as before.
- 3.13 Accordingly, the carbon calculator assumes that backup is provided by a fossil fuel mix of energy generation and reveals an expected lifetime emissions figure of 17,771 tCO₂ due to the back-up.

Loss of Carbon Fixing Potential

- 3.14 Construction of the development will involve the installation of infrastructure such as turbine foundations, access tracks and hardstandings etc. Where vegetation and/or peat is removed or covered, the vegetation will no longer be able to photosynthesise and therefore, its ability to fix carbon will be lost. In addition, changes to drainage can have an effect on the vegetation of peatlands. Accordingly, the carbon calculator assumes that the carbon-fixing potential is lost from both the area occupied by infrastructure as well as areas affected by drainage.
- 3.15 The carbon calculator does assume a worst-case scenario of 100% coverage of bog plants in areas where the vegetation is removed through construction or drainage. In order to demonstrate a worst-case scenario of the development's impact on drainage of the carbon fixing potential, the extent of drainage around infrastructure is given as 10 m expected and 5 m and 15 m as minimum and maximum values respectively.
- 3.16 In accordance with the calculator's methodology, the total emissions attributable to the loss of carbon accumulation by bog plants is equivalent to 832 tCO₂ over the operational period of the wind farm. This emissions figure is based on a development footprint plus the area affected by drainage and assumes 100% mire habitat cover.

⁷ Dale, L., Millborrow, D., Slark, R. and Strbac, G. (2004) Total Cost Estimates for Large-Scale Wind Scenarios in UK, *Energy Policy*, 32, 1949-56. First published in *Power UK*, Issue 109, entitled: 'A shift to wind is not unfeasible'.

⁸ DBEIS, Digest of United Kingdom statistics 2018, Available online from: <https://www.gov.uk/government/statistics/digest-of-uk-energy-statistics-dukes-2018-main-report> (Last accessed 09/10/18)

Loss of Carbon Dioxide from Removed Peat (Direct Loss)

- 3.17 Peat probing was undertaken at the Upper Ogmore site between 21 and 22 September 2017 by Ramboll. The findings of the surveys have been used to determine the baseline peat depths within the site boundaries. Following an update to the location of T3 further intrusive surveys and peat probing were undertaken between 4 and 10 June 2018 by RSK. The findings of these were used to create a Peat Depth Map; Figure 8.1 in Volume 3. Peat depths vary across the site but are generally quite thin. Thicker peat is found in a localised area close to the site entrance.
- 3.18 In the following calculations, the calculated areas and volume of peat affected by tracks and other infrastructure aim to represent a realistic worst case and assume the following:
- New roads include the running width of 4.5 m, shoulders of 0.25 m each side and additional width of 2.0 m to account for drainage.
 - The site is divided into two areas for foundation inputs to represent the two hub height wind turbines being installed. Area 1 includes the three smaller turbines, whilst area 2 includes the four larger turbines. All other infrastructure requirements are the same across the site.
 - Excavated area around turbine foundation assumes a 1:2 slope. This is conservative given the shallow depths to bedrock on the site but will allow for working area around the base.
 - The area at the surface is limited by the proximity to the track and hardstanding (taken as 12m for the conservative case) as an overlap of these areas would be double counting. This is illustrated in Figure 3.1 displaying the expected values for area 2. Table 3.1 provides a summary of the dimensions used for area 1 and area 2.

Figure 3.1 Area 2 Foundation excavation dimensions

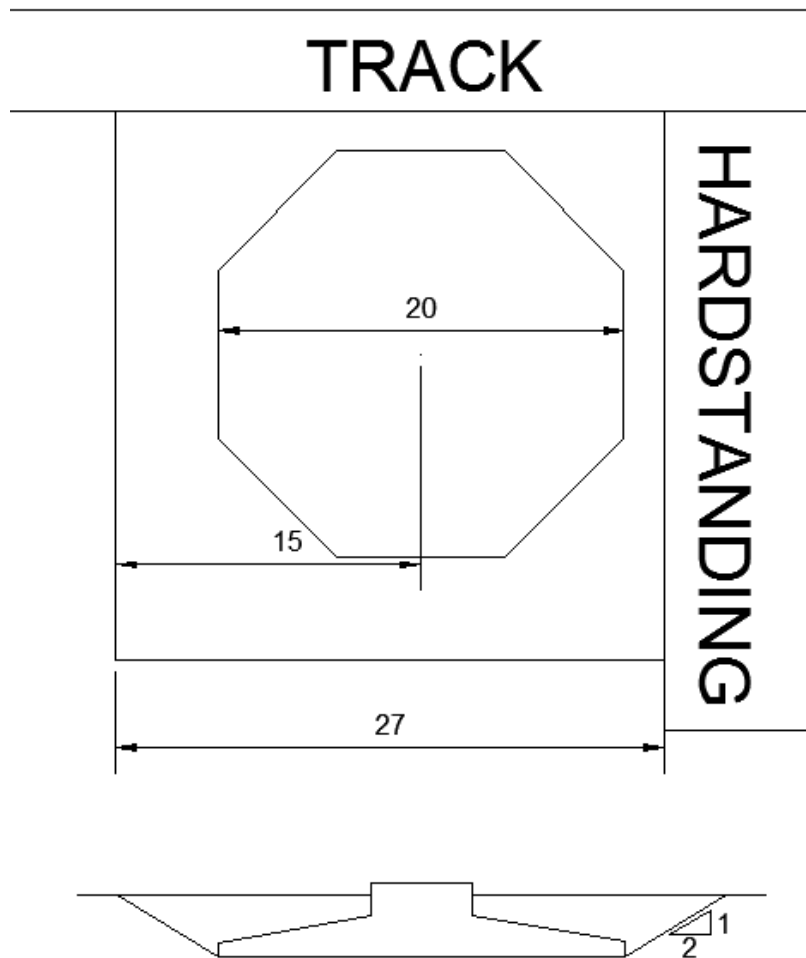


Table 3.1 Foundation excavation dimensions

Turbine Foundations	Area 1			Area 2		
	Expected value	Minimum value	Maximum value	Expected value	Minimum value	Maximum value
Width/length at base (m)	18	16	22	20	18	25
Depth of excavation (m)	3	2.5	3.5	3	2.5	3.5
Half width/length at surface (m)	15	13	18	16	14	19.5
Width/length at surface (m)	27	25	30	28	26	31.5

- Peat volume is modelled with vertical sides at the outer extent of the excavation.
- Borrow pits are excavated to their maximum extent.

- 3.19 No detailed analysis of peat samples has been performed for the site so values for the carbon content of dry peat (% by weight) and dry soil bulk density (g cm^{-3}) were taken from the latest online calculator tool.
- 3.20 The carbon calculator applies the full depth of excavation for turbine foundations to estimate peat removal for the turbine foundations and hardstandings. This has been corrected to use only the predicted peat depth at these locations.
- 3.21 The carbon calculator calculates the total volume of peat removed over the footprint of the wind farm to be 21,188 m^3 . The total expected amount of direct CO_2 loss, attributable to peat removal is calculated to be 10,741 tCO_2 .

Loss of Carbon Dioxide from Drained Areas left in Situ (Indirect Loss)

- 3.22 Carbon is also lost from peat habitats through drainage that occurs in the peat around the proposed development's infrastructure. The carbon calculator tool and associated guidance refers to this CO_2 loss as an "indirect loss". The extent of the site affected by drainage is calculated assuming an expected, minimum and maximum extent of drainage around each drainage feature e.g. turbine foundation, tracks etc. Although the extent of drainage is heavily dependent on topography, the analysis itself assumes relatively level terrain.
- 3.23 The carbon calculator tool calculates the area surrounding the wind farm infrastructure that is within the extent of drainage (10 m) and derives the CO_2 emissions resulting from this process. The total expected CO_2 loss from drained peat is 11,078 tCO_2 . There are two calculations methods available. The IPCC default methodology⁹ has been used which produces more conservative results than a site-specific calculation.

Loss of Carbon Dioxide from DOC and POC loss

- 3.24 Additional CO_2 emissions from organic matter can occur as carbon dioxide and methane can leach out of peat that is restored to conditions where the water table depth is higher after restoration than before restoration and is a further consideration of the carbon calculator. Dissolved Organic Carbon (DOC) is defined as the organic matter that is able to pass through a filter (range in size between 0.7 and 0.22 μm). Conversely, Particulate Organic Carbon (POC) is that carbon that is too large and is filtered out of a sample.
- 3.25 Only restored drained land has been included in the calculations within the carbon calculator for DOC and POC, because if the land is not restored then the carbon has already been lost for excavated peat.
- 3.26 The carbon calculator calculates that there will be no CO_2 lost due to DOC and POC leaching over the operational life of the wind farm.

Total Loss of Carbon Dioxide from Impact on Peat

- 3.27 The following calculations on total loss of CO_2 from the impact on peat have been based on a number of key assumptions (some of which are built into the tool itself), specifically in relation

⁹ IPCC, 1997, Revised 1996 IPCC guidelines for national greenhouse gas inventories, Vol 3, table 5-13

to peat in order to demonstrate a worst-case scenario using on-site data with input from ecology and hydrology specialists. In summary, these assumptions are:

- 100% of the area potentially affected by the wind farm is covered in peat forming mire habitat;
- The terrain is relatively flat with no existing drainage;
- Infrastructure dimensions for foundations, tracks and hardstandings include working areas;
- 100% of the carbon stored in the excavated peat will be lost as carbon dioxide and not reinstated on site;
- 10 m expected average extent of drainage to demonstrate a conservative expected scenario.

3.28 The combined expected impact of the development on peat over the operational lifetime of the development is therefore calculated as:

Table 3.2 CO₂ Losses from impact on peat

	CO ₂ from plants	+	CO ₂ loss from removed peat	+	CO ₂ loss from drained peat
Loss tCO₂=	832 tCO ₂	+	14,867 tCO ₂	+	11,078 tCO ₂
Total Loss tCO₂=	26,777 tCO ₂				

4. CARBON GAIN DUE TO SITE IMPROVEMENT AND RESTORATION

4.1 Restoration of areas within the site can reverse emissions and act as carbon storage, reducing the total CO₂ emissions as a result of the development. For simplification however, no gains from restoration have been accounted for. Hydrology is a complex issue and it is difficult to determine the level of water increase across the site.

5. OVERALL CARBON BALANCE OF THE PROPOSED WIND FARM

5.1 The total emissions savings of CO₂ of the proposed development is calculated by comparing the emissions from the site due to windfarm development with the carbon-savings achieved by the windfarm while displacing electricity generated from coal-fired capacity, grid-mix or fossil fuel-mix. The results are summarised in table 5.1.

Table 5.1: Summary of the emission savings associated with the Proposed Upper Ogmere Wind Farm

	TOTAL EMISSIONS SAVINGS (tCO ₂ eq)		
	Expected	Minimum	Maximum
Coal-fired electricity generation	2,594,827	2,438,415	2,723,858
Grid-mix electricity generation	748,855	715,508	754,821
Fossil fuel-mix electricity generation	1,267,832	1,199,886	1,308,396

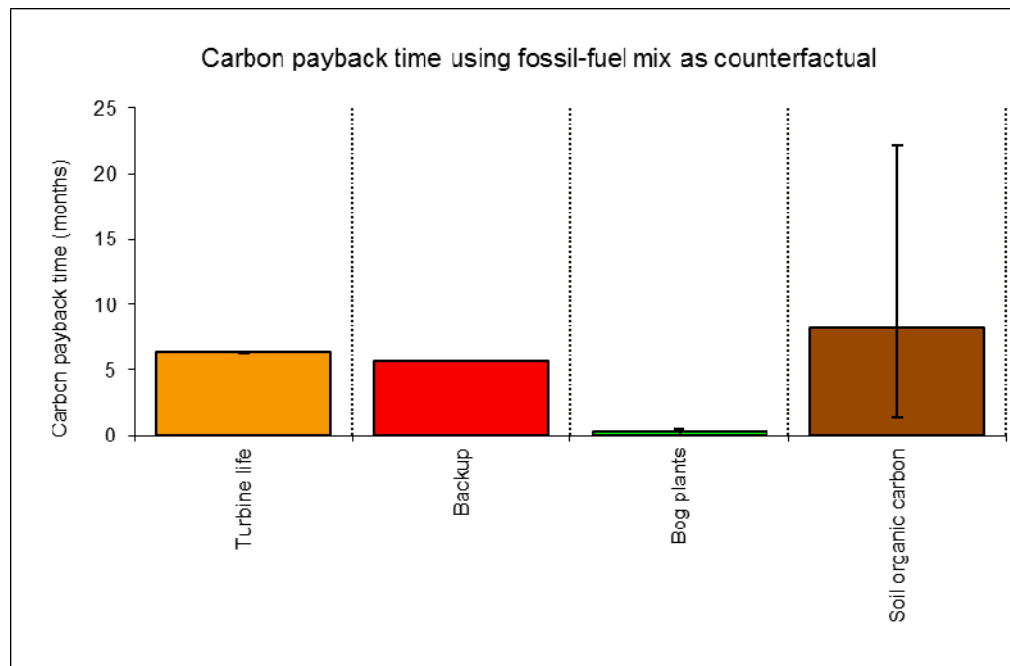
- 5.2 The carbon calculator reports the wind farm CO₂ emissions saving compared to those emissions from coal-fired, grid-mix and fossil-fuel electricity generation. Based on the expected annual energy output of the development (82,782 MW yr⁻¹), and the emissions associated with the development, the potential expected tonnes of CO₂ emissions saved per year over coal-fired electricity generation is 74,138 tCO₂; grid-mix generation is 21,396 tCO₂ and fossil-fuel mix is 36,224 tCO₂. Given that the total estimated CO₂ emissions for Bridgend local authority area was 822,500 t CO₂ in 2016¹⁰, the expected potential CO₂ emissions savings from the wind farm could account for the equivalent of 9.0%, 2.6 % and 4.4% of the total annual CO₂ emissions estimate for Bridgend when compared against coal-fired, grid-mix and fossil-fuel mix electricity generation.
- 5.3 Table 5.2 and Figure 5.1 below outline the overall carbon payback time for the 7 turbines and associated infrastructure described in the preceding paragraphs. The net emissions of CO₂ of the proposed development is calculated by deducting the total CO₂ gains produced by improvement of the site from the total CO₂ emissions lost from construction of, and impacts on peat from, the individual elements of the proposed development (described in the following paragraphs). Then, the net CO₂ emissions lost figure is divided by the wind farm CO₂ emissions savings over the other individual fuel types calculated, to reveal the payback time. It is considered that fossil fuel-mix emissions represent the most likely scenario.

Table 5.2: Summary of the carbon payback time associated with the Proposed Upper Ogmere Wind Farm

	EMISSIONS PAYBACK TIME (YEARS)		
	Expected	Minimum	Maximum
Coal-fired electricity generation	0.9	0.5	1.6
Grid-mix electricity generation	2.8	1.8	5.2
Fossil fuel-mix electricity generation	1.7	1.1	3.2

¹⁰ 2005 to 2016 UK local and regional CO₂ emissions, Available online from:
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/720677/2005-16_UK_local_and_regional_CO2_emissions.xlsx - Last accessed 09/10/18

Figure 5.1: Carbon payback time using fossil fuel mix as the counterfactual for Proposed Upper Ogmore Wind Farm



- 5.4 The conclusion of the model reveals that the proposed wind farm will likely effectively pay back its expected carbon debt from manufacture, construction, impact on habitat and decommissioning within 1.7 years, if it replaces the fossil fuel electricity generation method. Based on the minimum and maximum scenarios, the analysis shows that the payback time for fossil fuel-mix generation ranges between 1.1 and 3.2 years and illustrates that the proposed development is likely to generate 31.8 years' worth of clean energy based on the maximum worst-case value.

ANNEX A: CORE INPUT DATA

ANNEX B: CONSTRUCTION INPUT DATA

ANNEX C: PAYBACK TIME AND CO₂ EMISSIONS